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# NEW US PATENT APPLICATION

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## TITLE

"Device and method for computer peripheral access control"

## PRIORITY CLAIM

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10           The invention lies in the general field of computer devices. It concerns in particular a device for controlling peripherals by means of applications executed on a multi-application computer system.

15           In current multi-application systems, the applications have access to a peripheral through a software layer known as the peripheral driver. This driver makes it possible to export an abstract and generic (for a given operating system) view of a given peripheral.

20           On the one hand this abstraction makes it possible to simplify the design, development and information-carrying ability of the applications. On the other hand, the communications between several applications and the peripheral are centralised and co-ordinated by the peripheral driver. This makes it possible to share a peripheral between several applications, whilst preserving the integrity of the system.

25           The converse is that this abstract view of the peripheral causes a major handicap in a system where a high performance level is necessary. In addition, having regard to the abstraction of the peripheral by the pilot, the applications cannot entirely exploit the particular capacities of the peripherals, since the applications must conform to the protocol for communication with the driver. The applications cannot communicate directly with the peripheral interface.

30           In order to attempt to resolve these problems, several isolated solutions have been proposed.

          First of all the direct memory access (DMA) mechanism is known,

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for the transfer of data between the central memory and a given peripheral without the intervention of the central unit (CPU).

This mechanism allows an application to specify the address of a buffer block and the implied size in the next command.

5           However, on the one hand, fairly generally, the current peripherals can use an address only in physical form (not in virtual form) and, on the other hand, in a multi-application system, the operating system sets up a virtual memory management unit (MMU) in order to switch more easily between the memory spaces of the applications.

10           Because of this, in a standard multi-application system, each request involving a direct memory access (DMA) mechanism therefore passes through the operating system (OS) in order to convert the virtual addresses supplied by the application into physical addresses which can be understood by the peripheral involved. The operating system is once again used.

15           A method, described in US Patent 5 659 798 ("Method and system for initiating and loading DMA controller registers by using user-level programs", Blumrich) adds a few functionalities to the operating system and an associated hardware mechanism in order to avoid the operating system in programming by direct memory access (DMA). It uses in particular an address decoding module  
20 inserted on the bus system, and a particular initialisation of the virtual space of each application. The application can then directly supply the physical addresses and the sizes of the buffers, whilst guaranteeing the integrity of the system.

25           This method for preventing access to the operating system is however limited to the programming of the direct memory access mechanism, and in no way makes it possible to access the programming of the whole of the interface of a peripheral.

30           The I2O protocol can also be cited, using a specific input/output processor (IOP), placed between the central memory and the peripherals, and intended to relieve the central unit (CPU) of the processing of the interrupts during high-throughput processings.

In this protocol, a software driver is developed which is common to

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an entire class of peripherals (for example all the network interfaces), specific to an operating system. Each peripheral manufacturer in this class then develops a specific software driver which will be executed on the IOP.

There is then found a reduction in the processing of the tasks specific to a particular class of peripherals by the operating system. However, this is achieved at the cost of an increase in the level of abstraction of the access to the peripherals by the applications (with commands controlling a single driver common to an entire class of peripherals).

The problem formulated here is then to provide direct access  
10 without abstraction to different applications executed on a multi-application  
system, whilst guaranteeing the integrity of the system.

The invention relates firstly to a device for sharing and controlling access to peripherals for a computer system comprising a central processor (CPU) and at least one input/output peripheral having a physical control interface accessible to the central processor,

characterised in that said device has:

means for the faithful reproduction, in the form of a virtual interface, of the physical interface of at least one peripheral,

means of interception, by said virtual interface, of all the requests  
20 and data exchanged between the central processor and the peripheral,  
controlled by a pre-determined application executed in the system,

means of possible modification of said requests and data intercepted according to at least one pre-determined criterion.

It will be understood that, through this arrangement, the applications executed on the system can access the peripherals directly, without passing through the driving unit, and by therefore choosing a level of abstraction of the commands adapted to their needs. It is then possible for each application to specialise the programming of the peripheral in order to best use its performances according to the required result, specific to said application.

The creation of a virtual interface reproducing almost identically the physical interface of the peripheral makes it possible to carry out access

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virtual memory mechanism to the accesses to the peripherals, with:

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understood that the virtualisation of a physical interface, composed of a set peculiar to the physical registers peripheral, or physical io-pages, consists of the association of physical io-pages with virtual io-pages in the addressable memory space in the application. As in the case of the virtual memory, the association of each virtual io-page with its physical io-page is allocated attributes allowing control of the integrity of the system when there is access to the physical io-page by several applications. This is because qualifying each virtual io-page, these attributes make it possible to modify the data read or written by the application through its virtual io-page. In addition to the access authorisation rights in read and/or write mode, these attributes contain a bit mask. Each data item written by the application in a virtual io-page, enabled by its attributes to be modified, is transmitted to the physical io-page passing through the mask. The data running over the reverse path, from the physical io-page to the virtual io-page of an application, also passes through the mask.

According to a preferred arrangement, the reproduction means in the form of virtual io-pages of a physical interface peripheral comprise:

- a virtual memory space reserved for the image of the physical interface, peculiar to each application executed by the computer system, containing the virtual io-pages of the application,
- a means for linking the addresses of these virtual memory spaces to the physical interface address, containing the physical io-pages.

According to a particular embodiment, the interception means comprise :

- on the one hand an interface with the bus connected to the central processing unit, and an interface with the bus connected to the peripherals,
- on the other hand an address decoding means.

The address decoding means makes it possible to determine which accesses must be modified in order to take account of an integrity criterion for the system.

According to a more particular embodiment, the modification means comprise a means of filtering the requests intercepted by the interception means, according to at least one criterion stored in a memory means.

5           According to an even more particular embodiment, the filtering means is incorporated in a modifiable memory device.

          According to a first embodiment, in the hardware, the device is composed on the one hand of a module inserted between the central processing unit and the peripherals bus and on the other hand a software  
10       element previously stored in a memory device of the central processing unit and executed by the operating system when the system is initialised.

          The invention relates more generally to a telephone, a photographic apparatus, a printer, a scanner, a camera, a computer, a facsimile machine, a television receiver or an audio/video player, characterised in that  
15       these data processing appliances include a device as briefly described above.

          The invention also relates to an information storage means which is removable, partially or totally, and which can be read by a computer or a microprocessor storing portions of code of a computer program, making it possible to implement the method succinctly described above.

20           The invention also relates to a computer program product which can be loaded into a programmable apparatus, containing portions of code for implementing the steps of the method as briefly disclosed above, when the program is executed on a programmable apparatus.

          The description and the drawings which follow will give a better  
25       understanding of the aims and advantages of the invention. It is clear that this description is given by way of example, and has no limitative character. In the drawings:

- Figure 1 depicts in the form of a block diagram a computer system of a conventional type;
- 30       - Figure 2 depicts schematically the software architecture executed on a computer system according to the one depicted in Figure 1;

- Figure 3 depicts functionally the place of the device according to the invention in the computer system;

- Figure 4 depicts, in functional diagram form, a hardware implementation of the device and method according to the invention;

5           - Figure 5 depicts an example of an addressing space in a computer system where there reside two applications sharing the same peripheral;

- Figure 6 is a flow diagram of an execution diagram of the method according to the invention;

10           - Figure 7 gives an example of a mechanism used for the direct implementation of a DMA engine by the application, without the intervention of the operating system.

15           - Figure 8 illustrates, in functional diagram form, a variant embodiment of the hybrid hardware and software type of the device and method according to the invention.

In general terms, the invention finds an application in a computer system of a conventional type, such as the one illustrated in Figure 1 in the form of a block diagram.

20           Such a computer system has, on a processing board 1, connected together by an address and data bus 2:

1 – a central processing unit 3, for example of the Pentium type, (registered trade mark of Intel);

2 – a random access memory RAM 4 ;

3 – a read only memory ROM 5 ;

25           4 – a certain number of peripherals P connected to the address and data bus 2 by interfaces  $P_A$ , including an internal memory  $P_B$ , these peripherals comprising notably:

- a screen 6 with a screen interface 6A and an internal memory, not shown;

30           - a keyboard 7 with a keyboard interface 7A and an internal memory, not shown;

- a CD-ROM drive 8 with a CD-ROM drive interface 8A and



an internal memory which is not shown;

- a hard disk unit 9 with a hard disk interface 9A and an internal memory which is not shown;

- a network 10 with a network interface 10A and an internal memory which is not shown;

- a floppy disk drive 11 with a floppy disk drive interface 11a and an internal memory which is not shown.

Each of the elements illustrated in Figure 1 is well known to the person skilled in the art of information processing systems. These elements, known per se, are therefore not described here.

The random access memory 4 stores data from variables and intermediate processing results, in memory areas, bearing, in the description, the same names as the data whose values they store.

The read only memory 5 is adapted to store, for example, in areas which, for convenience, have the same names as the data which they store:

- the operating program of the central processing unit 3, in an area "program".

The central processing unit 3 is adapted to implement the computer peripheral access control method which will be disclosed below.

The invention applies notably with regard to the management of accesses to the peripherals 6 to 11 by software applications, that is to say in practice with regard to the communication bus 2 (for example of the PCI type in the remainder of the description) between the processor of the central processing unit 3 on which an operating system and applications are executed and the peripherals 6, 7, 8, 9, 10, 11 (the term resource will also be used in the remainder of the description in accordance with current usage, in order to designate peripherals).

As illustrated by Figure 2, a peripheral interface has both a hardware part and a software part.

The hardware part consists of a "daughter" board, plugged onto the main board or integrated into one of the silicon circuits fixed to the main board, for example the screen interface 6A, the network interface 10A, or the

disk interface 9A.

The associated software part is a so-called peripheral driver program, specific to each peripheral, for example here a screen driver 6', a network card driver 10' and a hard disk unit driver 9'. These drivers  
5 conventionally form part of the operating system 12, executed by the central processing unit 3.

The software part 15 of the computer system, finally, contains applications, such as for example Internet browser software 13, or video animation software 14. These applications 13, 14 are also executed by the  
10 central processing unit 12 and send many successive requests in read or write mode to the different peripherals which they need at a given time; screen 6, network 10, hard disk unit 9.

These applications are executed in parallel in a multi-application system.

15 Before describing any further the device and method according to the invention, information will be given relating to the computer system peripheral registers.

In general terms, the set, like the one denoted 9a in Figure 1, of programming registers of a peripheral like the one denoted 9 in Figure 1, can be  
20 divided into three groups:

1/ the state registers RE: these make it possible to know the state of the peripheral. For example, they contain information indicating that the peripheral has terminated the last request which it has received, or that it is ready to process another one.

25 This type of state register RE is intended to be solely read by one application, without there ever being a write operation by the application in this state register RE.

2/ the parameter registers RP: these registers RP are accessible to an application 13, 14 both in read and write mode.

30 They make it possible to make known to the peripheral 9, 10 the different parameters of a request which will follow. For example, these parameters include the cylinder, sector and head numbers in the case of a disk

controller 9A, or the address of writing the next packets when a network card 10A is received.

Neither reading nor writing in these registers RP triggers any particular process with regard to the peripheral itself, except the storage of parameters.

3/ The control registers RC : These registers are generally useful only in writing mode.

This is because it is by writing in a control register RC that the order of triggering a request is transmitted to the peripheral.

The value transmitted to the peripheral by the writing in this control register can contain a last decisive parameter, such as the type of request (transmission request, reception request, etc), but the value transmitted may also be arbitrary and, in this case, it is the simple fact of writing in such a register RC which triggers the peripheral command.

The definition of these three types of peripheral register leads logically to the definition of protection models which must guarantee the operating system vis-à-vis the manipulation of these registers RE, RP, RC by applications 13, 14. There are then four main types of protection:

**(A) Guarantee of the integrity of the data and of the code of the other applications in the course of execution.**

Typically, the operating system 12 must guarantee, in the case of access to a peripheral 9, that an application 13 cannot overwrite a memory area (in the random access memory 4 of the system) of another application 14 when data are received.

This constraint can be ensured by filtering the memory addresses, or more generally the parameters, supplied by the application 13 to the peripheral 9.

**(B) Guarantee that the manipulation by a given application does not interfere with the interaction of the peripheral with the other applications.**

It will be understood that, for example, an application 13 must not be able to issue a general reset instruction to the peripheral, when other

applications 14 are not prepared for such a reset.

This constraint may be ensured by filtering the control instructions sent by each application 13, 14.

**(C) Guarantee that the result of the reading of a state register does not cause an error in an application.**

It is for example clear that the information indicating that the last request has been executed (a bit in a state register RE) must be able to be read only by the application 13 responsible for this particular request. However, this information must not be read by another application 14 which has just sent a new request which has not yet been interpreted by the peripheral 9.

On the other hand, information indicating that the peripheral 9 is available and ready to process a new command must be accessible to all applications 13, 14.

The reading of the state registers RE must therefore only be partially filtered.

**(D) Guarantee of correct distribution of the data intended for the different applications.**

If an example is taken here of the management of a peripheral of the disk controller type 9A, it is found that, when data are read on a disk 9 by an application 13, the data in a sector are recovered by the application 13 by reading them one after the other in a specific input/output port of the interface 9A.

After each reading, the following data item is available on the port. If a second application 14 is enabled to read this port, the first application 13 generating the reading instruction will suffer the loss of at least some of the data which it is to read, these data being read by the second application 14.

For a peripheral of the disk controller type 9A, the operating system 12 must therefore filter the accesses in read mode to this type of data register.

The device according to the invention, a general configuration of which in hardware implementation form is illustrated in Figure 3, is composed of a module 16 inserted logically between the pair formed by the central

processing unit 3 and the random access memory 14 on the one hand and the bus 2 of the peripherals 6, 9, 10, on the other hand (it is a case there in some way of a component serving as an interface between the processor and the PCI bus).

5 To facilitate an understanding of the remainder of the description, the cache memory 17 of the central processing unit 3, connected to the latter by a system bus 18, has also been illustrated here. A bridge 19 has also been depicted, for arbitrating and computing accesses to the random access memory 4 and which is connected to the said memory by a memory bus 20. These  
10 components are known per se to the person skilled in the art.

Functionally, the module 16 described here by way of non-limitative example then includes successively:

- an input/output bus interface 21 connected by the input/output bus 2' to the pair formed by the central processing unit 3 and the memory 4 by  
15 means of the bridge 19,
- a programmable logic unit 22,
- a input/output bus interface 23 connected to the address and data bus 2.

The programmable logic unit 22 (for example implemented in the  
20 form of an ASIC) intercepts all the accesses in read and write mode on certain shared peripherals, and can modify the data transferred during these accesses, in accordance with a pre-programmed scheme, defined when the computer system is initialised (when the computer system is started up), by the operating system 12.

25 The programmable logic unit 22 of the module 16 has notably:

- a vector field accessible in the physical space of the central processor 3 in an area 160 (Figure 5) and making it possible to link the addresses of the virtual io-pages to the physical io-pages,
- a local memory 25 of the module 16 containing notably bit  
30 fields 132, 142 (Figure 5) specifying the filtering patterns for the installed applications 13, 14.

It will be understood that the operating system 12 can thus make

available to applications 13, 14, specifically modified to take advantage of the invention, a direct access to the peripherals connected to the module 16, thus guaranteeing the integrity of the operating system 12 (that is to say in particular by satisfying conditions (A) and (D) defined above.). This is explained by the  
5 fact that all the data passing between the applications 13, 14 and the peripherals pass through the programmable logic unit 22.

More precisely, the programmable logic unit 22 is composed (see Figure 4) of an address decoder 24, a local memory 25 and a programmable filter 26, disposed for example on an electronic card 27, alongside the  
10 input/output bus interfaces 21, 23.

The module 15 is inserted in series with the PCI bus (in the case of a bus of the PCI type) connected to the random access memory 4.

The input/output bus interface 21 connected to the central processing unit 3 sends to the address decoder 24 the addresses included in  
15 the requests sent to the peripherals, in read or write mode. According to the address decoded in a request and the direction of transfer (read or write), the address decoder 24 selects a filtering pattern in the local memory 25 (said local memory being initialised by the operating system 12 when the computer system is started up).

20 The data item included in the request is sent to the programmable filter 26 connected to the local memory 25 and in which the filtering pattern is applied to this data item. This filtering pattern indicates to the filter 26 the function to be applied individually to each of the bits of the data item. Thus the filter 26 can either leave the bit unchanged, or force it to 0, or force it to 1.

25 Each of these filtering patterns constitutes a criterion for checking the integrity of the system.

The modified data item issuing from the programmable filter 26 is then sent to the input/output bus interface 23 connected to the bus 2 of the peripherals and indirectly to the peripherals.

30 The device according to the invention also has a software part, which supplements the hardware part formed by the module 16.

This software part is necessary for correctly exploiting the

functionalities of the module 16 by means of the applications 13, 14 and the operating system 12.

To this end, when the system executed on the central processor 3 is initialised, the operating system 12 installs, in the virtual memory space 130, 5 140 (Figure 5) of the applications 13, 14, an access 133, 143 to the physical address space 170 in a particular decoding area 131, 141 of the module 16, referred to as the virtual io-pages area. This is effected for each application 13, 14 liable to request access in read or write mode to a particular peripheral (for example, the disk unit 9A). It should be noted by way of clarification that the 10 memory addresses 133 and 143 correspond to the virtual memory addresses peculiar to each application, whilst the areas 131 and 141 are visible in the physical addressing space for the processor 3. Thus, the virtual io-pages of the peripheral interface 9A are situated in the physical memory space 131, 141 and in the virtual memory space 130 of the application 1 in the area 133, and in the 15 virtual memory space 140 of the application 0 in the area 143.

The size of the virtual io-pages areas 131, 141 is equivalent to the size of the memory space occupied normally by the physical interface 9A of the peripheral 9 in question and containing the physical io-pages.

The application 13, 14 reads and writes the data exchanged with 20 the physical interface in the io-pages 131, 141.

The operating system 12 next initialises, for each application 13, 14, two vector fields 160, 161 of the module 16, specifying the correlation between the addresses of the virtual io-pages 131, 141 and the addresses of the physical io-pages of the peripheral 9A.

25 Finally, the operating system 12 initialises, for each application, an area 133, 143 in the local memory 25 of the module 16, corresponding respectively to the virtual io-pages 131, 141, with the filtering patterns (the number of filtering patterns varying according to the peripherals) to be applied to each access of the application 13, 14.

30 It should be noted that the patterns are partially identical for the peripheral. During the filtering, the DMA addresses (the parameters of the requests) are for example filtered differently in order to take account of the

translation scheme of the virtual addresses/physical addresses of each application for the same peripheral. On the other hand the patterns of the control registers will potentially be identical.

By way of clarification Figure 5 then depicts an example of an addressing space in a computer system where there reside two applications 13, 14 sharing the same peripheral 9.

The operating system 12 can gain access, through its virtual space 120,

- on the one hand to the vector fields 160, 161 (of the module 16), and to the two bit fields 132, 142 containing the filtering patterns of the virtual io-pages 131, 141 for each of the two applications 13, 14 (sharing the same peripheral 9) respectively,

- and, on the other hand, to the registers contained in the physical interface 9A of the peripheral 9.

Each application 13, 14 has access, through its virtual memory space 130, 140, in addition to the central memory normal for its execution (not shown), only to the specific area 131, 141 decoded by the module 16.

In Figure 5, the value N corresponds to the size of the physical interface 9A accessible to the central processor 3.

The value M corresponds to the size of the bit field necessary for coding all the filter corresponding to the physical interface. For example, if the size of the physical interface is 64 bytes, that is to say  $64 \times 8 = 512$  bits, then it is each of these 512 physical io-pages bits that the module 16 must filter. Relying on an example illustrated by Figure 7, each bit can be left unchanged, or forced to 1, or forced to 0. An elementary bit field must therefore have at least one of these three behaviours. By coding the behaviour itself in binary form, it occupies 2 bits (4 values). Finally, the size N necessary for coding all the 512 bit filters is  $512 \times 2 = 1024$  bits, that is to say  $1024 / 8 = 128$  bytes.

The value K corresponds to the size of the vector field necessary for describing the translation between the addresses of the virtual io-pages 131, 141 and the addresses of the physical io-pages 9A. Given the high number of possibilities of coding the translation means, only the two extremes will be



evoked:

- either the translations are fixed and non-modifiable, and, in this case, the size of the vector field is 0;
- or the translation of each virtual io-page address is described individually. Calling the size of the physical address bus (3, 4, 5 bytes or more), q, each vector field then occupies a space of  $K=q*M$  bytes.. Taking again the example of the interface containing 64 bytes of io-pages, the size of the vector field therefore occupies on a 32-bit bus (4 bytes)  $4*64=256$  bytes.

10 With regard to the method of controlling access to the peripherals, it then comprises the following steps, illustrated by Figure 6.

In a first step E1, as has just been seen, when the computer system is started up, the operating system 12 initialises the local memory 25 of the module 16 by sending the filtering patterns to it, to be applied to the addresses of the relevant io-pages of the shared peripheral (these filtering patterns previously being recovered from a memory of the system in the form of a bit field, for example).

20 The module 16 then waits in a step E2 until it receives a request from an application 13, 14 for reading or writing at the addresses of the virtual io-pages 131, 141. This request is intended for the shared peripheral 9.

25 In the case of a write command coming from the central processing unit 3 (a command sent by an application 13, 14 executed by the central processing unit 3), the data item is modified in a step E3 in accordance with what has been disclosed. The data item is then applied to the address and data bus 2 on the peripherals side in a step E4, via the interface 23, in order to transmit the data item to the corresponding physical io-page.

30 In the case of a write command on a virtual io-page, the read request is transmitted to the peripheral in a step E5 in order to read the corresponding physical io-page. Then the device 16 awaits a response from said peripheral in a step E6. The data item to be modified is then the one coming from the bus 2 on the peripherals side. This data item is then modified in a step E7, and then the data item once modified is applied to the bus of the

processor 2' at the level of the central processing unit 3, in a step E8.

In the example already cited in Figure 7, the module is used notably to guarantee this integrity when blocks are transferred by the DMA mechanism 102 proposed by the peripheral 9. When the application 13 is initialised, it requests from the system virtual access to the peripheral 9, requesting a virtual address area 103 which will be used for transferring data, 64 kilobytes in the example. Knowing the physical addresses 105 of the transfer area 103 of the application 13, the operating system executed on the processor 3 initialises the filtering pattern of the DMA address register in the bit field 132 accordingly; knowing that the buffer area 105 of the application 13 extends from 0x0010.0000 (in hexadecimal base) to 0x0010.FFFF, the filtering pattern must leave bits 0 to 15 unchanged, force bits 16 to 19 and 21 to 31 to 0 and bit 20 to 1. Thus, whatever the value written by the application 13 in the DMA register of virtual interface 133, the value sent to the physical interface will always be in the area 105 belonging to the application 13.

It will be understood that a peripherals sharing device has indeed been set up, guaranteeing the integrity of the system during accesses in read or write mode from and to the peripherals in all types of register in these peripherals. It is clear that the applications must be modified to take advantage of direct access to the peripherals which is then offered to them, and to be able to send commands without any abstraction, to the closest of the commands which can be executed by each peripheral.

This is a principally hardware device, insofar as, apart from the initialisation of the local memory 25 of the module 16 by the operating system 12, the other tasks of processing accesses to the peripherals are totally taken over by the module 16 according to a hard-wired logic, for example.

This method makes it possible to obtain protection of the accesses as far as the granularity of the bit, since it is capable of monitoring each individual access. In addition, it makes it possible to discharge the CPU cycles (of the central processing unit 3) of the operating system 12, delegating the check on the data transmitted by the module 16.

As a variant, the programmable logic unit 22 is inserted in each of

In a variant embodiment of the hybrid type including both a hardware and software device and illustrated by Figure 8, the device is in the form of a more flexible logic, in terms of programmability.

In summary, the local processor 28 scrutinises all the accesses of the applications 13, 14 in read mode and in write mode on the virtual io-pages 131, 141 in order to cause them to undergo any filtering processing before propagating access directly on the physical interface 9A in the decoded areas.

Likewise, the operating principle remains identical to that disclosed  
15 in Figure 6 and during the description given with reference to this figure.

20                   According to yet another variant embodiment, purely software this  
time, the device uses the memory management unit (MMU) of the central  
processing unit 3, known to the person skilled in the art. It should be stated that  
the memory management unit MMU makes it possible to associate pages, and  
therefore virtual addresses, seen by the applications 13, 14, with physical  
25                   pages, actually present in the random access memory 4.

Redirecting the use of the mechanism for translating virtual pages  
30 into physical pages, it is then possible to emulate the virtual io-pages  
mechanism. This is because, by treating in a particular manner the exceptions  
generated by the memory management unit MMU during accesses by the

applications 13, 14 to the virtual io-pages addresses 133, 143, it is possible to control the data read and written by these applications from and to the peripherals.

- 5 Naturally, the present invention is not limited to the details of the embodiments described here by way of example, but on the contrary extends to any modifications within the capability of the person skilled in the art.

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